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Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio

1954

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The studies I am to discuss were aimed primarily for the unsewered urban fringe areas. However, the same progress in transportation and electrification which has enabled modern living in fringe areas has also brought modern living to the farm. Fundamentally, the waste problem and its solution are much the same. The farmer is indeed in the enviable position of having ample space, possibly a choice of soil and equipment, ability and habits which make it convenient to take care of waste disposal facilities.

The number of individual household sewage disposal systems in this country probably now exceeds six million, serving some 24 million persons, with recent new residence construction running some 30 per cent to such systems. The common system is a septic tank followed by subsurface application to the soil by either shallow trenches or deeper pits. The septic tank serves as a settling, digestion and solids storage tank, functionally preparing the sewage for the necessary further treatment and absorption in the soil. If surface and subsoils are suitably absorptive the shallow trench system is preferred practice; if not, and if porous soils are reasonably available at deeper depths, pits with open joint walls, called seepage pits, are used. As the latter penetrate the deeper

* For presentation at the meeting of the North Atlantic Section, American Society of Agricultural Engineers, August 24-26, 1954, at the University of Vermont, Burlington, Vermont.

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soils they are of greater hazard to ground water pollution. Where the soil offers no reasonable absorption possibilities, the common alternative is a subsurface sand filter, either in the form of a trench or a bed, discharging to a surface watercourse. The cesspool, which is similar in construction to a seepage pit but receives raw household waste, finds scattered use but it is generally recognized as a source of difficulty in other than the most porous soils. Because of this and its pollutional liabilities the cesspool is not recommended nor approved in many states and local areas.

With entry of the federal government in private housing, to the extent of insuring mortgages, it became evident, in attempting to settle on design specifications, that there was considerable diversity in state and local standards over the country. It became evident too that there were many unresolved problems in this field due partly to an underlying scarcity of factual data upon which to base proper design. This led to joint sponsorship, by the federal Housing and Home Finance Agency and the Public Health Service, of studies on household sewage disposal systems. These were conducted by the Public Health Service's Robert A. Taft Sanitary Engineering Center at Cincinnati, Ohio, the active work starting in 1947.

A poll of local health departments over the country in 1947 indicated that only 40 per cent of the systems then existing had been installed under organized control. Prominent among the difficulties existent were evidences of failure to design on the basis of proper soil

investigation, the tendency to skimp on tank capacity, poor layout, careless construction, and problem areas amounting to misapplication of this type system in a totally unsuitable soil environment. However, design and installation shortcomings were but partly responsible for the many failures. At least equally responsible were the delinquencies in servicing the septic tanks, overdue in more than 50 per cent of the calls according to servicemen, resulting in sludge spillovers and consequent clogging of the soil absorption system.

During the period of investigation by the Public Health Service, 1947-1953, some 350 household sewage disposal systems in several areas over the United States were examined in the field. At the Center in Cincinnati, 33 full size household type septic tanks were operated experimentally to determine influencing elements, such as size, shape, compartmentation and flow appurtenances. Studies of the effects of ground garbage, detergents, water softener brines, and sodium hydroxide, were also conducted in the full size tanks. Laboratory experiments on anaerobic digestion, under the influences abovementioned, and on the soil clogging effects of sewage, effluents, and home laundry waters were undertaken. Experimental studies of the soil water percolation test were made, and factual data on soils, climate and soil-water characteristics developed in agricultural circles were evaluated for use in this field. A brief presentation of some of the results of these studies and their applications follows. The details on these and allied matters are contained in reports now available or in prepara-

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tion on the work (1,2,3,4).

The volume of wastes from individual homes, as reflected in metered water consumption, varies considerably, depending on house size and living habits. Winter water consumption averages 39 gallons per person per day, ranging from 8 to 150 among different homes. Automatic dish washing machines and garbage grinders add but little to the waste volume but automatic sequence laundering machines increase water use by some 17 gallons per person per day on the average. Among homes of four or less bedrooms, which represents about 99 per cent of the recent home building in the United States, the highest per capita water consumption, and the highest person occupancy per bedroom, are found in the smallest homes. These decrease as the size of home increases, within the group abovementioned.

The variable character of residential wastes is influenced by individual family habits and practices in the use of cleansing materials and appliances. Variation among different installations is wide. Changes in ownership and occupancy of a particular system also introduces variation. As a consequence the yardstick, number-of-occupants, is losing favor in preference to the number-of-bedrooms as a more stable measure of loading potentiality. Inherent in this measure is, for instance, capacity for week-end or overnight guests. Many times the initial occupancy and appliance circumstances, as well as those consequent to future ownership changes, are unknown. Coupling this with growing trends toward general use of household appliances, thoughts in some quarters run to designing for the entire loading potentiality in the initial system. This has merit in that ownership changes are often made

without knowledge of what limitations there may be in the existing sewage disposal facilities.

Concerning studies of septic tank design elements, the importance of capacity became very evident. Beyond effecting the solids removal function, capacity is required for solids storage. The amount of storage capacity is a matter of choice, depending on the cost of such storage as compared with costs of cleaning septic tank at intervals governed by storage capacity. Both field and laboratory studies indicate that the larger the tank the better the solids removal performance. Tanks having 125 to 175 gallons per capita capacity were found to effect average suspended solids removal in household practice. In experimentally operated tanks a 500 gallon single tank removed 60 per cent suspended solids as against about 80 per cent for a 2,000 gallon single tank. Tanks of some 300 gallons and smaller capacity quickly consumed solids storage space and thereafter failed in solids removal. Because of relatively high tank servicing costs in the United States liberal capacity is of economic advantage. Other advantages accrue, such as improved solids removal and less interference with sustained performance in the longer operating intervals.

Among newer household appliance factors the only one requiring expansion of tank capacity is the garbage grinder. Field studies indicate 77 per cent increase in sludge and scum accumulations, with the increase in scum alone, 210 per cent, and in sludge alone, 31 per cent, over the non-garbage installation. Increase in flow due to automatic laundering machines was not significant in effect on tank capacity, although it necessitates adjustment of soil absorption design areas, as

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does garbage also. No tank adjustments for detergent use, nor for ion exchange water softener brine waste, are indicated.

Septic tank capacities necessary to provide reasonable suspended solids removal performance during intervals of about ten years between cleanings, on the average, are listed in table 1. The table also includes the sizes necessary to provide the same average ten year operating interval where ground garbage is involved, a 50 per cent increase in capacity.

Table 1 - Minimum liquid capacities, household septic tanks

No. bedrooms	Min. liq. cap. (gallons)	
	Without garbage	With garbage
2 or less	500	750
3	600	900
4	650	975
Over 4	160/bedroom	240/bedroom

Rectangular, vertical round and similar straight vertical side tanks perform equally well at the same capacity. Non-straight vertical side tanks, such as horizontal rounds, also perform well if designed to realize solids storage capacity equal to the others. Liquid depths of 2½ to 5 feet gave good performance better at the shallower depth.

Multi-compartmentation studies indicate usefulness of such arrangements, in two ways. They may be utilized to broaden the variety of acceptable tanks, with performance at least equal to a single tank of the same capacity. Two, three, and four equal compartments are examples of this. They may also be utilized to obtain higher performance over a single tank of equal capacity, but the design narrows to certain arrangements

to accomplish this aim, such as two compartments, with one-half to two-thirds total capacity in the first. Suspended solids removals as high as 80 per cent may thus be obtained, as compared with 60 for the single tank of the same capacity. This advantage does not accrue in three equal compartments, nor in two with a small first compartment, nor fully in four equal compartments. In comparing relative costs consideration should be given not only to first cost but the cost of servicing multi-compartments. The well designed single tank still enjoys a record of good performance in well drained soil areas. Under less favorable circumstances, including those of space limitation for relocation of absorption systems, multi-compartmentation may find most interest.

It was found experimentally that the location of the bottom of an outlet tee determines the distribution of available storage space among scum and sludge. Further, scum and sludge accumulations approach limiting distances above and below the bottom of outlet fixture, beyond which solids retention fails. For sludge, such distances are related to liquid surface area, and range from 1.8 feet for 12.5 square feet surface area to 0.5 feet for 30.0 square feet, under simulated household flow patterns. Limiting distance for scum, not investigated experimentally, but with limited field experience, is suggested as three inches for practical purposes. Deducting the volumes represented by the above distances from capacity, the residual space is submerged solids capacity. This may be apportioned among scum and sludge proportional to accumulation rates. The apportionment amounts to 25 per cent for submerged scum storage space in non-garbage tanks; 44 per cent in garbage tanks. The outlet bottom is

set accordingly. For practical convenience outlet design statistics, expressed as percentages of tank liquid depth, are presented in table 2. These apply for straight vertical side tanks. For other shapes, such as horizontal rounds, a separate computation must be made. Total freeboard is suggested as outlet projection above water line plus one inch.

Table 2 - Location top and bottom of outlet tee or baffle.

Total liquid tank capacity (gals)	Tank receiving sewage		Tank receiving sewage and garbage	
	Projection above water line (% of liq. depth)	Penetration below water line (% of liq. depth)	Projection above water line (% of liq. depth)	Penetration below water line (% of liq. depth)
500	~~10~~ 12	22	~~16~~ —	~~33~~ —
750	~~11~~ 12	24	~~17~~ 18	38
1,000	~~11~~ 12	26	~~17~~ 18	41

In designing inlet tees or baffles, projection to one inch below roof and downward penetration the same distance, from inlet invert to bottom of fixture, as the outlet, are suggested. A three inch drop from inlet invert to water line is customary. In multi-compartmentation, each compartment was provided with inlet and outlet fixtures in the studies. The three inch drop to water line might best be provided in the first compartment.

The soil absorption system involves factors as the volume of waste, its clogging characteristics after passage through the tank and the absorption characteristics of the soil on site. A very high unit waste loading is imposed on the soil in such systems, in comparison to rainfall and irrigation loadings. Rainfall averages 30 to 50 inches per year in the United States, with extremes of 150 inches, resulting in some 20 to 40 inches of absorption, reaching 100 at the extreme. Irrigation amounts

te about 100 inches applied per year. In contrast, household absorption system trench bottoms receive from 200 to 1,000 inches of effluent annually, running to over 2,000 inches in extreme cases. To this volume is added the complicating influence of sewage constituents.

Physical, biological, and chemical influences in soil absorption of effluent were studied. The physical plugging of soil pores increases as the amount of suspended matter applied increases. Biological influences in agricultural water spreading amount to clogging soil pores with biological bodies and by-products or destruction of soil structure by biologic activity. In septic tank effluent application, however, the biologic activity tends to reduce the clogging tendencies of other factors. Chemical clogging, through ion exchange and breakdown of soil structure, is a common agricultural irrigation problem, due to waters relatively high in sodium. This factor also is present in the household system because of increase in sodium ratio as waters are used in household operations.

Clarified fresh sewage clogs soil more rapidly than septic effluent pound for pound of solids; effluent solids from tanks receiving ground garbage and sewage similarly clog soil more rapidly than those of sewage tank effluent; disinfected effluent clogs soil more rapidly than biologically active effluent. Concerning the influence of household appliances and practices, other than garbage, it is found that a slight shortening of absorption field life may attend inclusion of waste water softener brines. Use of detergents instead of soap may also slightly shorten absorption field life under some circumstances.

Evaluating various influences on soil absorption characteristics, it appears that two, namely the increase in waste volume attending use of automatic clothes washers, and the change in clogging character of waste where ground garbage is included, should be recognized for readjustment of the soil absorption system design values originally derived from the Ryon studies of the 1920's. The adjusted design values are given in table 3.

A basic problem is the estimation of absorption characteristics of a soil and its interpretation in the particular site environment. Considering the latter, there are certain soil environments not at all suitable for housing development on the basis of individual soil absorption type disposal systems. These include impervious soils, pervious upper soils underlain by impervious soil or water table within four feet of the surface, and pervious soils lying in an impervious underground basin. In the latter cases, the disarming success of test results at the shallow depths, fortified sometimes by history of successful operation of an existing isolated system or two can lead to failure when the large loadings of a subdivision are imposed. Such areas have been trouble spots under subdivision development.

Several clues to soil permeability are of some value in appraising soil, but the only really safe basis is the percolation test. Agricultural soil survey reports are helpful in the United States. Visual inspection of soil texture, structure, and color on site are also of interest. Texture, or elemental particle size distribution, is reliable as a clue to pore space and water absorption quality only in sandy soils. In heavier

soils the elementary particles clumped into secondary larger particles, termed structure, becomes the more important clue as the secondary particles govern pore space and water absorption value. Color may indicate history of favorable or unfavorable oxidation conditions through movement of air and water. Bright reddish-brown to yellow colors throughout a soil profile are typical of favorable soil. Light gray topsoil, and drab, mottled subsoil reflects the opposite.

The quantitative percolation test for application in this field was proposed by Ryon (5) who developed an empirical relationship between soil absorption capacity, as measured by a water percolation test on site, and permissible effluent loading per unit of trench bottom area. As most of the systems studied by Ryon had operated some 20 years before failure, systems designed on the basis of that work have a 20 year life expectancy, under conditions of loading up to the 1920's.

Investigation of the percolation test was included in the Public Health Service studies. As a result a suggested fundamental and objective procedure is offered. This procedure is essential for clay soils, and cases where no experience with either the test methods or a particular soil, is available. As local experience is gained the procedure may be used to check possibly shorter procedures suitable for local circumstances.

Suggested percolation test

1. Number and location of tests: Six or more tests shall be made in separate test holes spaced uniformly over the proposed absorption field site.

2. Type of test hole: Dig or bore a hole, with horizontal dimensions of from four to twelve inches and vertical sides, to

the depth of the proposed absorption trench. In order to save time, labor and volume of water required per test, the holes can be bored with a four inch auger.

3. Preparation of test hole: Carefully scratch the bottom and sides of the hole with a knife blade or sharp pointed instrument in order to remove any smeared soil surfaces and to provide a natural soil interface into which water may percolate. Remove all loose material from the hole. Add two inches of coarse sand or fine gravel to protect the bottom from scouring and sediment.

4. Saturation and swelling of the soil: Carefully fill the hole with clear water to a minimum depth of twelve inches over the gravel. By refilling if necessary, or by supplying a surplus reservoir of water, such as in an automatic siphon, keep water in the hole for at least four hours and preferably over night. Allow the soil to swell over night. This saturation procedure insures that the soil is given the opportunity to swell and approach the condition that it will be in during the wettest season of the year. Thus the test will give comparable results in the same soil whether made in a dry or a wet season.

In sandy soils containing little or no clay the swelling procedure is not essential and the test may be made as described under Item 5C, after the water from one filling of the hole has completely seeped away.

5. Percolation rate measurement: With the exception of sandy soils percolation rate measurements shall be made on the day following the procedure described under Item 4, above.

A. If water remains in the test hole after the over night swelling period, adjust the depth to approximately six inches over the gravel. From a fixed reference point measure the drop in water level over a 30-minute period. This drop is used to calculate the percolation rate.

B. If no water remains in the hole after the over night swelling period, add clear water to bring the depth of water in the hole to approximately six inches over the gravel. From a fixed reference point measure the drop in water level at approximately 30-minute intervals for four hours, refilling six inches over the gravel as necessary. The drop that occurs during the final 30 minute period is used to calculate the percolation rate. The drops during prior periods provide information for possible modification of the procedure to suit local circumstances.

C. In sandy soils (or other soils in which the first six inches of water seeps away in less than 30 minutes, after the over night swelling period) the time interval between measurements shall be taken as 10 minutes and the test run for one hour. The drop that occurs during the final 10 minutes is used to calculate the percolation rate.

6. Additional criteria for judging soil suitability: In areas of shallow ground water, the depth to the water table shall be determined. If for any extended period during the year the water table is normally at a depth of less than four feet, the results of the percolation test should be applied with caution. The case also warrants special consideration if impermeable layers are found at depths less than four feet.

Suggested design areas for soil absorption trench type systems are presented in table 3. These take into account recent water consumption data, effects of garbage grinders, and automatic sequence washers, the original Ryon allowable sewage loading data (5), and additional data on clogged systems, treated by modern statistical approaches to arrive at the values given.

Table 3 - Percolation rate and design absorption areas.

Percolation rate, (time required for water to fall one inch - in minutes)	Required absorption area (Square feet of absorption trench bottom per bedroom)			
	Without garbage grinder or auto. washer	With garbage grinder	With auto. washer	With both garbage grinder and auto. washer
2 or less	50	65	75	85
3	60	75	85	100
4	70	85	95	115
5	75	90	105	125
10	100	120	135	165
15	115	140	160	190
30	150	180	205	250
45	180	215	245	300
60	200	240	275	330
Over 60	Unsuitable for shallow absorption system. Investigate for seepage pit or subsurface filter arrangement.			

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In this area the question of freezing may be of interest. Sources of experience close to installation and servicing of household systems in our northern states and in Canada were solicited in this connection. The incidence of freezing in the usual shallow household system is very small. Unprotected excavation and frozen backfill should be avoided. Pipe lines under areas usually cleared of snow, such as driveways, should be insulated. There have been troubles from failure to observe these precautions.

From the physical simplicity and minimal maintenance demands of the household septic tank-soil absorption system one would little suspect that its behavior is as intricate and effective as its highly mechanized, professionally operated community brother, nor that it operates under normal load variations which are ofttimes quite upsetting to the latter. Nonetheless, the household system is not foolproof and can fail from carelessness in the home and from failure to remove accumulated solids from the tank when necessary. Reasonable use of household disinfectants and cleansing agents is not considered seriously damaging to the system. Excessive use can cause serious damage. As for maintenance, annual gaging of tank scum and sludge will indicate their approach on the critical distances above and below the bottom of the outlet tee or baffle mentioned earlier (page 7), at either of which the tank should be cleaned. For practical gaging purposes a strip of turkish toweling tacked along a stick lowered vertically to tank bottom through an outlet tee or baffle and left in contact a few minutes will indicate sludge level. A hinged flap on a stick serves to locate bottom of scum and bottom of outlet. Many failures originate in delinquencies in removing accumulated solids from the tank, sometimes because the homeowner is not aware that there are maintenance responsibilities. A leaflet, "Septic Tank Care", (6) has been made

available in recent years to assist the homeowner in understanding the system and its responsibilities.

In considering the installation of a system, local guidance may be obtained, in areas with organized control, from the agency authorized to issue permits, approve proposed plans and inspect systems. If such assistance is not available it may be obtained from the county or state health departments.

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